Getting VR Right Then and Now … The Indispensable Role of Human Factors and Human-Centred Design

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Invited Essay

Getting VR Right Then and Now … The Indispensable Role of Human Factors and Human-Centred Design

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In the Beginning …

I recall with great pleasure attending the *Teleoperators & Virtual Environments* Conference in Santa Barbara and being one of the 'founders' of the journal *Presence*, all those years ago in 1990. This highly important event in the worldwide history of Virtual Reality (VR) enabled me to re-establish contact with some of the individuals who were, just three years previously, influential in kick-starting my career in VR, not to forget others who had significantly helped my research in the advanced robotics arena during the 1980s. The conference also brought new, like-minded and professional advocates together to form a community that has since seen many changes – some for the better, some for the worse – but a community that still persists to this day. And, apart from being the butt of 'typical Brit' jokes whilst hiking with certain attendees (Sheridan and Brooks) in the hills overlooking Santa Barbara Beach (my fault for wearing a formal shirt and tie, I guess!), I and probably all of those attending the conference had no idea at the time what an impact it would have on the international VR arena. Not only did the event create new VR 'disciples' who went forth and established their own significant research initiatives across the globe, but it also was the launch platform for a journal that has, unlike many others, stayed the course and is still delivering material of academic and real-world applications significance today.

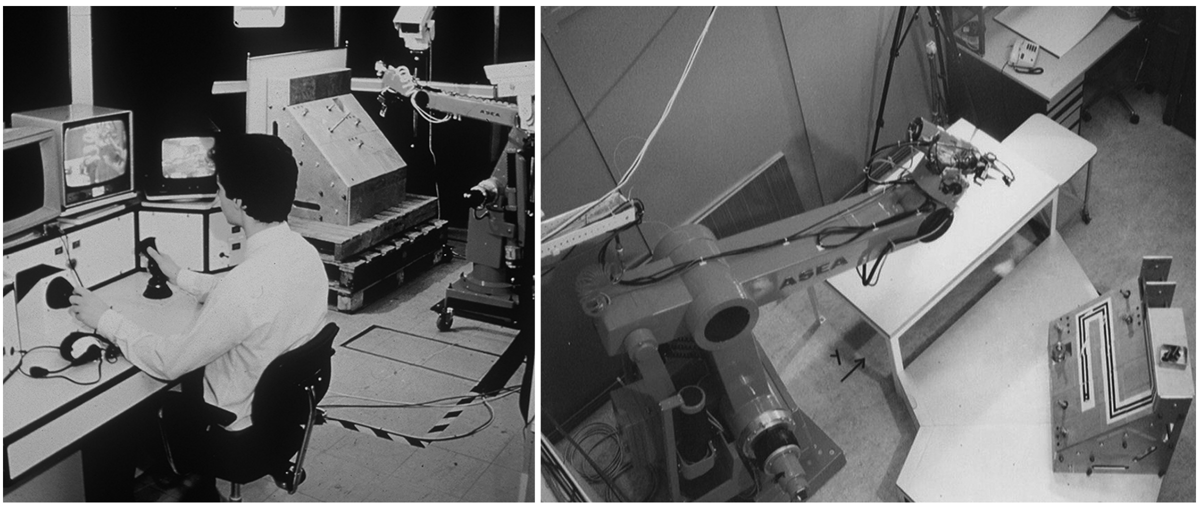

Figure 1. The original ESA 'Teleoperation & Control' experimental test bed

However, my 'newcomer's' poster participation in that conference was not my first exposure to VR. What was to become a career-changing experience actually occurred three years before this event. In the mid-1980s, my Human Factors (HF) research team at British Aerospace in Bristol, UK was undertaking Low Earth Orbit 'Teleoperation & Control' research projects for the European Space Agency, ESA (e.g. Stone, 1989; Figure 1). Whilst taking part in a Satellite Servicing Conference held at the NASA Goddard Spaceflight Center in Maryland during June, 1987, just by chance, I was introduced to Steve Ellis who invited me to visit him and his colleague Scott Fisher (both of whom were also at the *Teleoperators & Virtual Environments* Conference) at NASA Ames' Aerospace Human Factors Division in Moffett Field, California, with the aim of presenting the HF work of my UK team and its relationship to ESA's spaceflight efforts.

Immediately after the Maryland conference, I enthusiastically made the trans-continental journey to San Francisco; the visit to Ames took place the following day and included a tour of Fisher's Virtual Environment Workstation (VIEW) Lab. Equipped with a bulky prototype head-mounted display and an instrumented glove, I was instructed to use simple gestures to 'fly' towards and stand on the lowest step of on an ascending computer-generated virtual escalator. Later, I was positioned on the edge of a rotating virtual camshaft. Both demonstrations were, to put it mildly, awesome experiences (if not a little disorientating), even with the simple wireframe graphics at that time. The headset-and-glove technologies – the forerunners of what would become VPL's commercial EyePhone and DataGlove products – were like no kind of human-computer interface concept I had ever witnessed before.

Yet, despite the uniqueness of this VR experience, the one overriding lesson learned from Ellis and Fisher during that brief visit to the NASA Labs was how important they felt it was to put HF considerations first, before getting too excited about the amazing wearable and computer interactive technologies the VR community was beginning to produce with a vengeance. With my qualifications in HF, of course, this came as no surprise. However, a few years later I was forced to recall Ellis and Fisher's comments during a healthcare VR project that almost failed because of a 'technology push' mentality, but was pulled back from the brink thanks to a rethink based on HF principles.

In that one short visit, I concluded that this was the research path I wanted to take and that, on my return to the UK, I would renew efforts within the military and space projects being undertaken by my Human Factors Team at British Aerospace. However, that aspiration was short-lived, due to lack of interest within BAe (at that time) and the result of a governmental decision not to increase the UK's space research budget. Just one month after my visit to NASA, a certain notorious British Prime Minister, known widely as the 'Iron Lady', had decimated all attempts to establish the UK as a leading light in ESA's manned and robotic spaceflight (Gavaghan, 1987). The effect all this had on British space research teams, including my own, forced me to look elsewhere to pursue what I knew was fast becoming a significant development in the field of human-computer interaction.

That 'elsewhere' was the newly-established National Advanced Robotics Research Centre (NARRC) in Salford. Given the role of Project Manager overseeing research into robotic sensors, 'world modelling' and what was then called 'MMI' (Man-Machine Interaction), I was provided with a budget that enabled my small team to acquire a VPL *EyePhone* and *DataGlove* and a Polhemus *3-Space* tracking system. With those technologies, access to a Cybermotion K2A mobile robot, plus the ability to fund the development of a head-slaved stereoscopic remote camera system (Figure 2), a rudimentary pneumatic haptic feedback glove called *Teletact* (see Delaney, 2014), and a *Vision* transputer-based VR computer from the fledgling UK company Division Ltd, my team and I embarked on an ambitious HF research project called *VERDEX* – the Virtual Environment Remote Driving Experiment. Indeed, alongside the now-dwindling ESA research described earlier, and together with early plans for the *Teletact* system, the *VERDEX* project featured as a poster presentation at the 1990 NASA Conference in Santa Barbara (Figure 3). Later, the results of *VERDEX* were to appear briefly on the first UK TV documentary on VR, BBC Horizon's *Colonising Cyberspace*, alongside appearances by others from the 1990 event, including Tom Furness, Jaron Lanier, Scott Fisher, Howard Rheingold and Michael McGreevy.

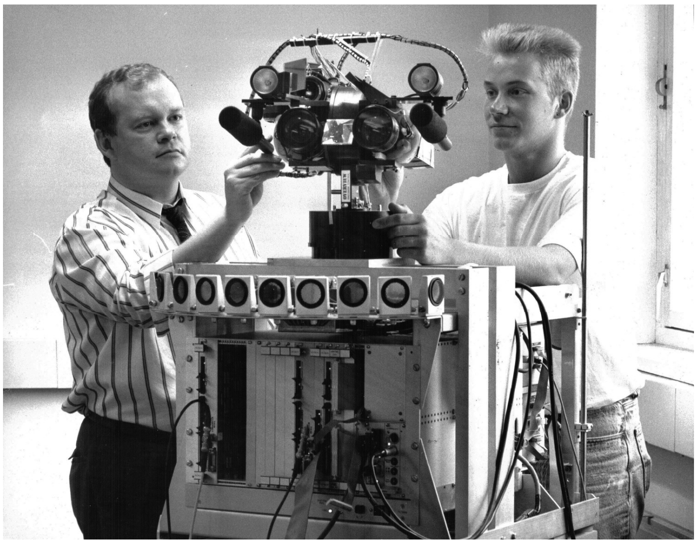

Figure 2. Early head-slaved stereoscopic camera prototype mounted on a Cybermotion K2A robot

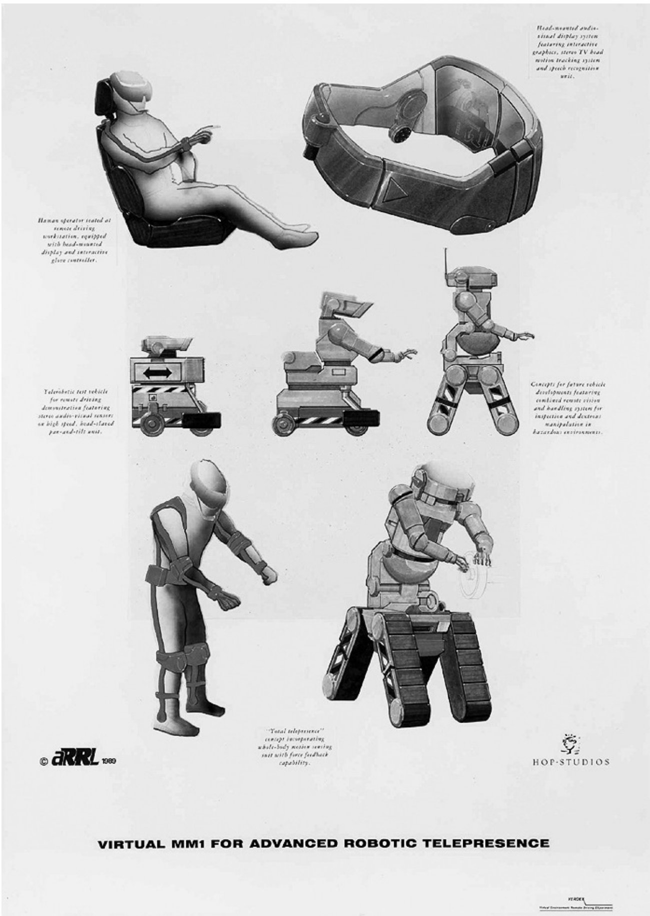

Figure 3. The Virtual Environment Remote Driving Experiment (*VERDEX*) – concept illustration

From Telerobotics to VR for Industrial and Healthcare Sectors

The early telerobotics-focused research enabled the NARRC team to go much further in the VR domain and, with the end of the Centres' governmental funding in sight, to turn our attention to the future challenge of introducing these technologies to applications in industry and healthcare. In 1993 we launched the UK's first *Virtual Reality & Simulation* initiative, uniquely fully funded by industry. *VRS*, as it was known, came about after an appearance on the BBC's *9 O'Clock News* early in January of that year when, after months of having to endure TV appearances of Virtuality's *Visette*-bedecked youngsters doing battle with virtual pterodactyls, wizards, skeletons and other characters, a VR user was seen for the first time navigating around a simple model of a Rolls-Royce jet engine – a model that was actually converted from the Company's computer-aided design (CAD) assets (Figure 4). Sponsored applications that followed the launch of *VRS* were diverse, to say the least – from modelling nuclear submarine compartments for maintenance training to the visualisation of new aisle and shelving designs for two well-known British supermarket chains. However, the one project, indeed product that evolved from early *VRS* investigations and that has had an enduring influence on my commercial and academic teams' approach to undertaking VR research and development projects in general was the Minimally Invasive Surgical Trainer (MIST$_{VR}$), a VR simulator designed to train surgeons in the skills of undertaking laparoscopic interventions.

Figure 4. Early VR system demonstrating a future aircraft engine maintenance concept (1992)

MIST$_{VR}$

MIST$_{VR}$ evolved from a project sponsored in 1994 by the UK's Wolfson Foundation and Department of Health, the overarching aim of which was to assess the potential of emerging Virtual Reality technologies to deliver cost effective training for future surgeons. In brief (see also Stone & McCloy, 2004; Stone & Hannigan, 2014), and in collaboration with clinical subject matter experts, I undertook a series of observational task analyses during surgical procedures which helped to isolate eight key task sequences common to a wide range of laparoscopic cholecystectomy (gall bladder removal) and gynaecological interventions. The analyses also helped me to define how those sequences might be modified or constrained by such factors as the type of instrument used, the need for object or tissue transfer between instruments, the need for extra surgical assistance, and so on. As a result of these early analyses, I decided that MIST$_{VR}$'s VR content should be designed to foster – and objectively assess – laparoscopic skills, *not* by training on realistic virtual human bodies (which were unachievable at the time), but on carefully selected task 'primitives', abstracted from the behaviours and events observed in theatre (these primitives included spheres, blocks, cylinders and wireframe task volumes of low visual detail, or low 'physical' fidelity). In addition, and moving more into the realm of Mixed Reality (MxR), I recommended that interaction with the abstracted visual elements of MIST$_{VR}$ was achieved using a built-for-purpose laparoscopic instrument frame, as shown in Figure 5. Early feedback from the users of MIST$_{VR}$ confirmed that the provision of a realistic instrument frame did much to accelerate their acceptance of MIST$_{VR}$ as a surgical skills trainer.

Figure 5. MIST$_{VR}$ Laparoscopic Surgical Skills Trainer

Eventually, MIST$_{VR}$ became the world's first part-task surgical skills trainer, adopted and evaluated on an international scale and as a *de facto* skills trainer by the European Surgical institute in Germany. But, more importantly, the background HF research and human-centred development processes demonstrated conclusively how VR training systems could benefit from – and, indeed, should be subjected to – a strong, underpinning Human Factors approach from the outset. I say 'eventually' for a good reason. Even though MIST$_{VR}$ was one of my most successful VR projects in those early days, that success came at a significant and quite embarrassing cost. My colleagues and I had been forced to learn a very hard lesson – a lesson that, with my Human Factors background, plus the formative experience gained in the Labs at NASA Ames some seven years prior should not have happened.

When the sponsorship from the UK funding bodies mentioned earlier came through (and, for the UK it was quite a sizeable budget at that), we went into 'technology-push overdrive'. We were unleashed and adamant! *Of course* surgeons would need stereoscopic displays (and autostereoscopic displays at that); *of course* they would need sophisticated multi-axis haptic feedback systems interfacing with realistic deformable models of human organs and tissue; *of course* they would need to see blood, fluid leakage and smoke and tissue congealment effects generated from the application of virtual diathermy. And that's what we did … tens and tens of thousands of

UK pounds later we had implemented nearly all of those features (with a Silicon Graphics *RealityEngine* underpinning them all – see Figure 6). Enter the surgical community … exit the surgical community. For them, stereoscopic viewing was not an issue and neither was haptic feedback, due to the small operating volumes involved, the small movements made and the strong monocular and lighting/shadowing cues that were available. Our anatomical models were too simplistic. And if we trained surgeons to 'operate' on virtual tissues and organs that demonstrated the deformable characteristics that were being shown on our Silicon Graphics system (which, incidentally, they stood no chance of ever being able to afford), then patients would die.

What had we done? This serious set-back gave my team and I a harsh reality check, one I have never forgotten to this day, embarrassing and costly though it was. Fortunately, the situation was recoverable and the final result, MIST_{VR} (as described earlier), was a success.

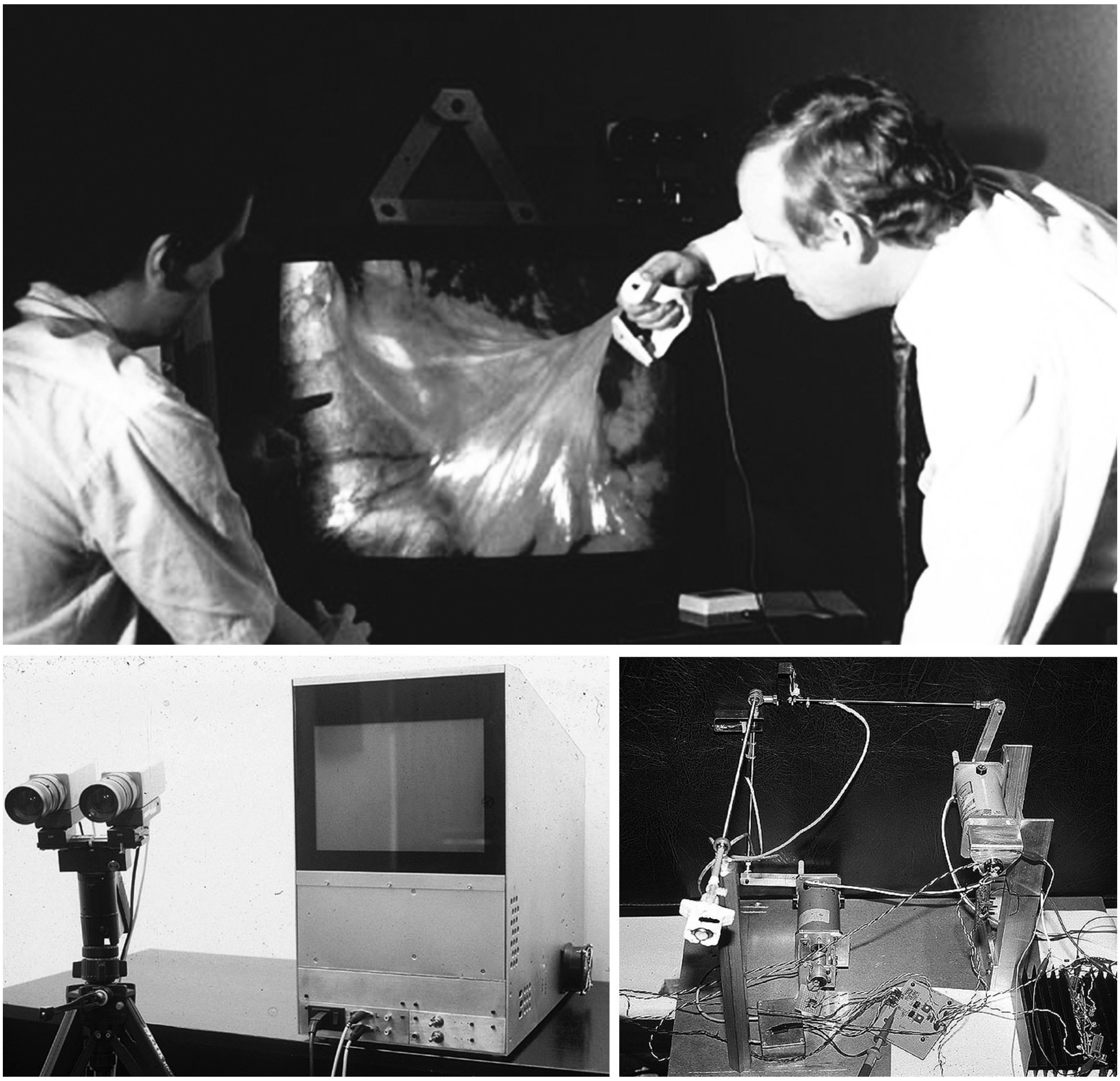

Figure 6. In pursuit of 'reality' for virtual reality surgical skills training (1994)
Upper image: deformable tissue on a Silicon Graphics *RealityEngine*
Lower images: prototype autostereoscopic display (left) and haptic feedback system (right)

Humans First, Technology Second

From that point on, I vowed that we would never undertake another VR (or AR or MxR) project unless we could demand that a proper human-centred design process was put in place from Day One, and that we had the involvement and engagement of key stakeholders and end users throughout the entire project lifecycle. 'Humans First, Technology Second' became our 'battle cry'. Of course, from time to time we would indulge in that 'fun' part of research often referred to as developing a 'technology demonstrator'. Who in the VR community does not? But for mainstream, large-scale projects, a sound HF approach was always mandated. Sometimes, customers would refuse such a 'luxury', claiming it would unnecessary time and cost to a project. Often they went away; often the alternative they eventually sponsored failed.

To this day, my team and I have strived to extol the virtues of incorporating HF knowledge into the development of VR, AR and MxR systems and, over the years since the MIST$_{VR}$ experience, a number of opportunities have arisen that have helped us to strengthen our arguments even further. For example, in the late 1990s, two defence VR projects came our way that not only enabled us to conduct a number of exciting Human Factors analyses, working with instructors, trainees and other stakeholders to deliver affordable and credible training solutions to the Royal Air Force and Royal Navy, it also set the scene for our team to deliver two more sophisticated Mixed Reality demonstrators in recent years.

The first Royal Navy Close-Range Weapons Simulators installed at the British shore base HMS Collingwood provide one example of how real equipment – in this case inert weapons removed from the original training establishment of HMS Cambridge (also a shore base) – could be used to augment the VR experience. Our observations and Human Factors analyses of gunnery trials and procedures at HMS Cambridge and elsewhere not only drove the choice of a Mixed Reality approach to the design of the final simulators, but also confirmed the need for an HMD-based solution for the VR training, based on the seaward scene-scanning behaviours of gunner/aimers and their onboard interaction with other naval personnel.

Furthermore, the control strategies of the two types of weapons considered in this project, the 20mm GAM BO and the MSI 30mm, confirmed that an MxR solution was essential. To operate the 20mm weapon, the gunner is normally strapped into the shoulder rests and has to use the full weight of his body in order to move the weapon in azimuth and elevation. In the case of the 30mm weapon, the gunner sits within a small open cabin to one side of the loading mechanism and operates the azimuth, elevation and firing functions of the weapon by means of a small control panel. These features, coupled with the choice of a partially face-enclosing HMD (affording a degree of peripheral vision to the wearer, both in azimuth and elevation), led to the delivery of a very successful training facility (Figure 7), with significant cost savings over live firing trials and much improved gunnery trainee performance (Stone & Rees, 2001).

Figure 7. Royal Navy gunnery ‘mixed reality’ trainer

A similar human-centred design philosophy was also adopted in the case of the Helicopter Voice Marshalling Simulators installed at the RAF Bases of Shawbury and Valley. These were originally designed to train *Griffin* (Bell 412) helicopter aircrew to monitor safety- and mission-critical aspects of the external environment through an open rear cabin door, verbally relaying important flight commands and situational awareness information to the pilot in order to guarantee an accurate and safe approach of the aircraft to a landing site or target object. As with the Close-Range Weapons Simulators described above, early Human Factors analyses of the Voice Marshalling Aircrew during flight operations suggested that a Mixed Reality solution was essential, combining the presentation to trainees of virtual images representing a variety of training scenarios using a partially face-enclosing, head-tracked HMD (as with the Royal Navy solution, summarised above) in conjunction with a simple wooden framework, the dimensions of which were based on the rear door area of the *Griffin* Helicopter (Figure 8). The wooden frame also supported the accurate positioning of safety handholds above and either side of the door, as found in the real aircraft, together with a mounting block for the purposes of attaching a standard issue RAF safety harness. Three such simulators were delivered and their success, in terms of mainstream and remedial training outcomes at a fraction of the cost of flying a real aircraft, has led to further developments of benefit to the RAF (Stone & McDonagh, 2001).

Figure 8. Helicopter Voice Marshalling 'Mixed Reality' Trainer

VR and Academia … the Story Continues

I left the volatile world of commercial VR in 2003, choosing to join academia and to excite and inspire students, not only to develop the appropriate design and software skills that are an essential component of their future careers, but also to embrace the importance of human-centred design in the development of content with appropriate task, context and interactive fidelity and in the exploitation of appropriate interactive technologies.

Between 2003 and 2012, my University team and I were given an excellent opportunity to look back on over two decades of involvement in the VR community and to undertake even more projects to emphasise the importance of HF in VR design. Building on the experiences described earlier, and courtesy of sponsorship from the UK Ministry of Defence via what was known as the Human Factors Integration Defence Technology Centre (HFI DTC; Barrett *et al*., 2006), we were able to undertake a range of stakeholder-led VR projects, from submarine safety training to counter-improvised explosive device awareness, and from field hospital surgical training to the development of a unique simulator for the UK's *CUTLASS* bomb disposal robot (Figure 9). The HFI DTC funding also enabled us to produce two key documents containing lessons learned and HF guidelines for VR, AR and MxR researchers and designers. These have been made freely available and are still very much in use today, including in my lectures to future generations of VR developers (Stone, 2008; Stone 2012).

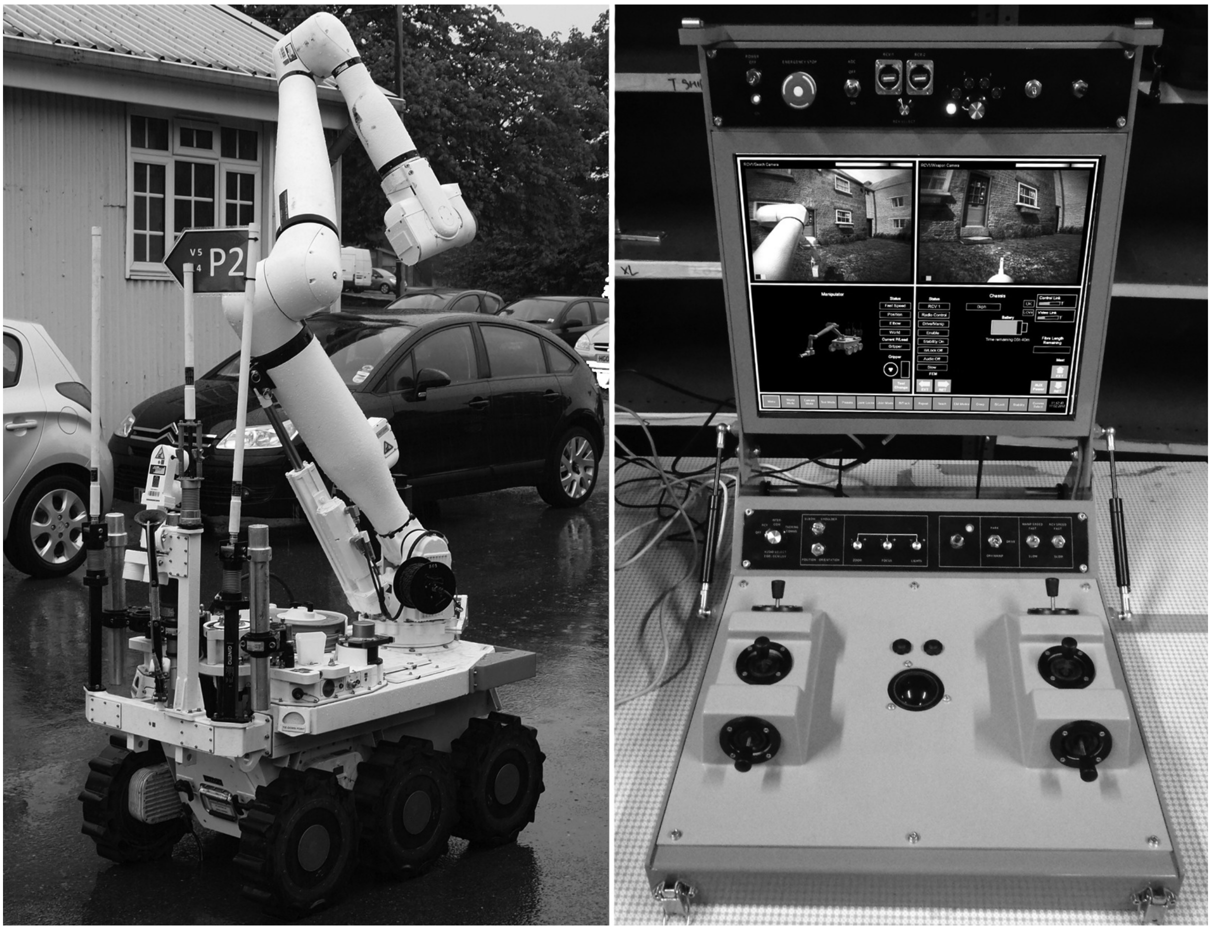

Figure 9. *CUTLASS* bomb disposal robot and remote vehicle/manipulator training simulator

The story continues, yet I often find myself coming full circle, drawing on the early NASA experience and the influential presentations at the 1990 *Teleoperators & Virtual Environments* Conference. Then it was VR and telepresence for applications in space and the nuclear industry. Now it is Mixed Reality for sophisticated command and control concepts. In many respects, Figure 10 suggests that, perhaps we have not come as far since the late ‘80s and early ‘90s than we may believe. In some respects that is very true. One has only to witness the frenetic activities on the Internet that have occurred as a result of VR’s recent ‘re-birth’ to see that the ‘newcomers’ to our established community are making the same technology-push mistakes their predecessors did all those years ago. Memories are short and warnings from the world’s VR ‘veterans’ are often ignored.

Nevertheless, we who have been involved in this arena for ages (and I’m not only referring to my team here) plough on, always in the hope that our ongoing achievements demonstrate best practices, evolved over three decades, to a technology-hungry new generation. The fact that our latest MxR Command & Control workstation bears a remarkable resemblance to NASA’s VIEW concept (Figure 10) is testament, I believe, not only to the harsh lessons learned over those three decades, but also to the enduring impact I experienced during my visit to Ames and my participation in the *Teleoperators & Virtual Environments* Conference, all those years ago.

Figure 10: Then and now – from NASA's Virtual Environment Workstation to a present-day mixed reality command and control test bed

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